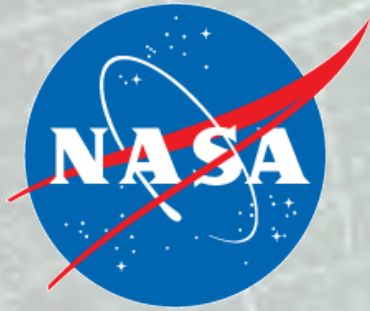


The background of the slide features a stylized representation of a celestial body, possibly a planet or moon, with a prominent ring system. The body is depicted as a bright, glowing sphere on the left side. To its right, a series of concentric, elliptical orbits are shown, each with a different color (blue, green, yellow, orange, red). A grid of thin, light blue lines covers the entire background, suggesting a coordinate system or a map of the sky. The overall aesthetic is scientific and futuristic.

The Evolution of the CCSDS Orbit Data Messages

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- 29-May-2018



Introduction

- Consultative Committee for Space Data Systems (CCSDS) established in 1982
- Develops international standards for space data communication and data exchange
- Technical branch of ISO Technical Committee 20, Subcommittee 13 (TC20/SC13)
- 6 Areas subdivided into 20+ Working Groups (one is Navigation WG (NavWG))
- NavWG Charter: provide "a discipline-oriented forum for detailed discussions and development of technical flight dynamics standards (orbit/trajectory, attitude, tracking, maneuver, pointing, orbital events, conjunction assessment, etc.)"
- NavWG includes regular membership representing 7 of 11 CCSDS Member Agencies.
- NavWG meets face-to-face twice per year, approximately monthly via telecon
- Since 2004, NavWG progress has been regularly reported at SpaceOps and the International Symposium for Space Flight Dynamics
- Trajectory information frequently needs to be exchanged between organizations
- Orbit Data Messages (ODM) standard developed specifically for this data exchange
- ODM is NavWG's most successful and widely infused international standard

Overview

- This presentation will describe:
 - The evolution of the Orbit Data Messages standard through its several versions
 - Infusion of the ODM into spacecraft operations in many if not most of the Earth's major space agencies
 - Some of the growing number of applications in which the ODM is being utilized

CCSDS Standardization Process Basics & CCSDS Spectrum

- Standards proceed through several progressively more mature levels:
 - Concept Paper, Proposed Standard, Draft Standard, and finally Recommended Standard
- Concept Papers and Proposed Standards are documents internal to a designated CCSDS Working Group
- Draft Standard is made available for external review and commentary
- To achieve the Recommended Standard status "at least two independent and interoperable prototypes or implementations must have been developed and demonstrated in an operationally relevant environment, either real or simulated"
- Recommended Standards are suitable for implementation in operations
- Recommended Standards available free on CCSDS website
- Historically, CCSDS printed paper copies of documents with colored covers (White, Red, Blue, Green, Orange, Silver, Pink ...); printed copies no longer produced, but the document color names persist

Orbit Data Messages "Version 0"

- The first Blue Book developed by NavWG's predecessor ("Panel P1J") was called "Radio Metric and Orbit Data"
- Published in 1987, consisted of 15 pages total: CCSDS "boilerplate" (7 pages) Orbital elements (2), reference system (1), tracking data (2), references (1), appendix (2)
- No mention of attitude/orientation or maneuvers
- Stated purpose was "to establish common recommendations for adequately exchanging data involved in orbit computation", but no format for the data is specified
- Important attributes such as required content, applicable units, a few constants and conversions, etc., were provided, but the format was entirely unspecified
- Notably, no "shall" statements in the document; numerous "should" statements
- Does seem to have informed the later development of the Orbit Data Messages Version 1 and another NavWG standard, the Tracking Data Message
- ISO 11103:1991 (Withdrawn)
- The "Radio Metric and Orbit Data" standard was finally retired in November 2003

Orbit Data Messages Version 1 (ODMV1)

- ODMV1 was the first standard published by the "new" NavWG, started late 1990's
- Previously no ISO international standard for representation of a spacecraft trajectory
- 2 data messages: Orbit Parameter Message (OPM), Orbit Ephemeris Message (OEM)
 - Originally OEM called "EPM" (Ephemeris Parameter Message), renamed Oct 2003
- Primary requirements: digital implementation, unambiguous specification and clear identification of applicable object, time system, units, and reference frames
- Detailed what was allowed for keywords, data line formats, syntax, units, time formats
- OPM/OEM shared common structure: Header Section, Metadata Section, Data Section
 - The Header Section provided basic identification information
 - The Metadata Section described forthcoming data (i.e., "data about data")
 - The Data Section provided the actual trajectory data
- OPM Data Section: Cartesian state vector, single epoch, had to be propagated
- OEM Data Section: Cartesian state vectors (epoch, position, velocity) of single object at chronological epochs, interpolated for arbitrary state, dynamic effects "built-in" to states
- Became CCSDS Blue Book in September 2004; ISO-22644:2006 in January 2006

ODMV1 Infusion

- Primary use case for ODMV1 was to provide a trajectory representation to be used by missions cross-supported between Agencies of the CCSDS
- While awaiting ODMV1 approval, the EPM prototype version was used for cross support between ESA/ESOC and NASA/JPL
- EPMs were used to support mutual tracking of ESA and NASA interplanetary spacecraft, especially during the arrival of the 2003 missions to Mars
- ESA's Mars Express and ROSETTA were tracked by NASA's Deep Space Network (DSN) antennas using EPMs
- JPL delivered EPMs to ESA/ESOC for contingency support for MER, MGS, Mars Odyssey, Cassini, Ulysses, and SOHO
- Use of EPM prototype in live operations helped to refine the ODMV1 recommendation, and validated the feasibility of the basic ODM concept
- Today OEMV1 is still used in regular operations at ESA/ESOC and NASA/JPL/DSN
- JAXA and ISRO also have the ability to process OEMs
- AGI's (Analytical Graphics Inc.) Satellite Tool Kit (STK) also processes OEMV1

The "ODMV1 Style"

- As ODMV1 was nearing publication, at the Spring 2004 NavWG meetings in Montreal, there was agreement among attendees: ODMV1 standard design would be model for future standards developed by NavWG; successive standards would be consistent
- This agreement set the mold for most of what has happened in the NavWG since, and there is still a major influence from the "ODMV1 Style"
 - Header section, Metadata Section, and Data Section
 - Use of ASCII, a common format used in all computing architectures
 - Mandatory and optional "keyword = value" (KVN) keywords with invariant order
 - One keyword/value pair per line
 - Common numerical formats
 - Clear definition of units that are ideally part of the International System of Units (SI)
 - Define format and content of data to be exchanged, but not transmission method
 - Use of Interface Control Documents (ICDs) jointly developed by exchange participants to capture special information not part of standard

Orbit Data Messages Version 2 (ODMV2)

- In mid-2005, SC13 and SC14 committed to work together on a modification to the ODMV1 standard that would accommodate new requirements
- New and changed features in the ODMV2 relative to the ODMV1:
 - Added third message type: Orbit Mean-Elements Message (OMM); allows ODM=>TLE and TLE=> OMM conversion
 - A 6x6 lower triangular form position/velocity covariance matrix was added
 - Optional acceleration components added to OEM position/velocity state vectors
 - Several other miscellaneous changes of lesser magnitude
- All changes in ODMV2 are optional, thus ODMV1 backward compatibility possible
- ODMV2 was published November 2009; ISO 26900:2012 was approved July 2012, and ISO 22644:2006 was retired

ODMV2 Infusion

- The OMM has been infused into the USSTRATCOM "Space-Track" web page (see <https://www.space-track.org/#/catalog>)
 - Here one can see TLEs and the associated OMMs right alongside each other
- One primary "new" application of ODMV2 relates to space situational awareness
- Pairs of space object trajectories can be analyzed to determine whether or not there are any close approaches/potential collisions within shared span of the ephemerides
- Several organizations use ODMV2 OEMs with covariance matrices for conjunction assessment
 - NASA's Conjunction Assessment Risk Analysis (CARA) operation for Earth orbiters
 - AGI's Commercial Space Operations Center (ComSpOC) for Earth orbiters
 - NASA's Multimission Automated Deepspace Conjunction Assessment Process (MADCAP) operation for Moon and Mars orbiters
- Open-source software OREKIT and NASA's GMAT process ODMV2

The ODM in XML Format

- In 2002, CCSDS Management Council (CMC) directive to use "PVL, or preferably Extensible Markup Language (XML) in CCSDS 502.0-R-2 Orbit Data Messages"
- XML formatting of ODM was not developed in time for ODMV1 or ODMV2 publication
- Navigation Data Messages XML Specification standard (NDM/XML) was published December 2010
- NDM/XML provided XML schemas for OPM, OEM, and OMM, as well as schemas for all other NavWG standards and instructions for coding instantiations
- An agency can elect whether to provide the Keyword/Value Notation (KVN) or the XML version, or both, as meets their requirements with respect to exchange partners
- One key concept that was incorporated in the NDM/XML standard was the concept of a "combined instantiation"
- In such an XML message, orbit data messages could be combined with instantiations of other NavWG standards that described attitudes, tracking data, and conjunctions
- A variant and extension of this concept will be leveraged in the "ODM of the Future" described later

Orbit Data Messages Version 3 (ODMV3)

- CCSDS requires a review of each standard every five years: reconfirm, retire, or revise
- In ODMV2's periodic review in 2014, decision to revise the standard led to ODMV3
- New use cases due to maturation of conjunction assessment processing and large-scale ephemeris exchange by such providers as ESA/ESAC, ComSpOC, and SDA
- OPM, OMM, and OEM are essentially unchanged in the ODMV3, but new use cases resulted in a new message: the Orbit Comprehensive Message (OCM)
- OCM aggregates/extends much content of 3 existing ODM messages into a single hybrid message, adds ability to describe force models, OD method used, more extensive covariance matrices, state transition matrices, perturbations
- OCM allows exchange of more detailed maneuver info than the simpler OPM
- New constructs and an emphasis on file compactness result in OCM style that departs significantly from the 2004 ODMV1 model
- ODMV3 will incorporate XML formatting material that is now in the NDM/XML standard
- ODMV3 is still in development; NavWG hopes to publish in late 2019/early 2020

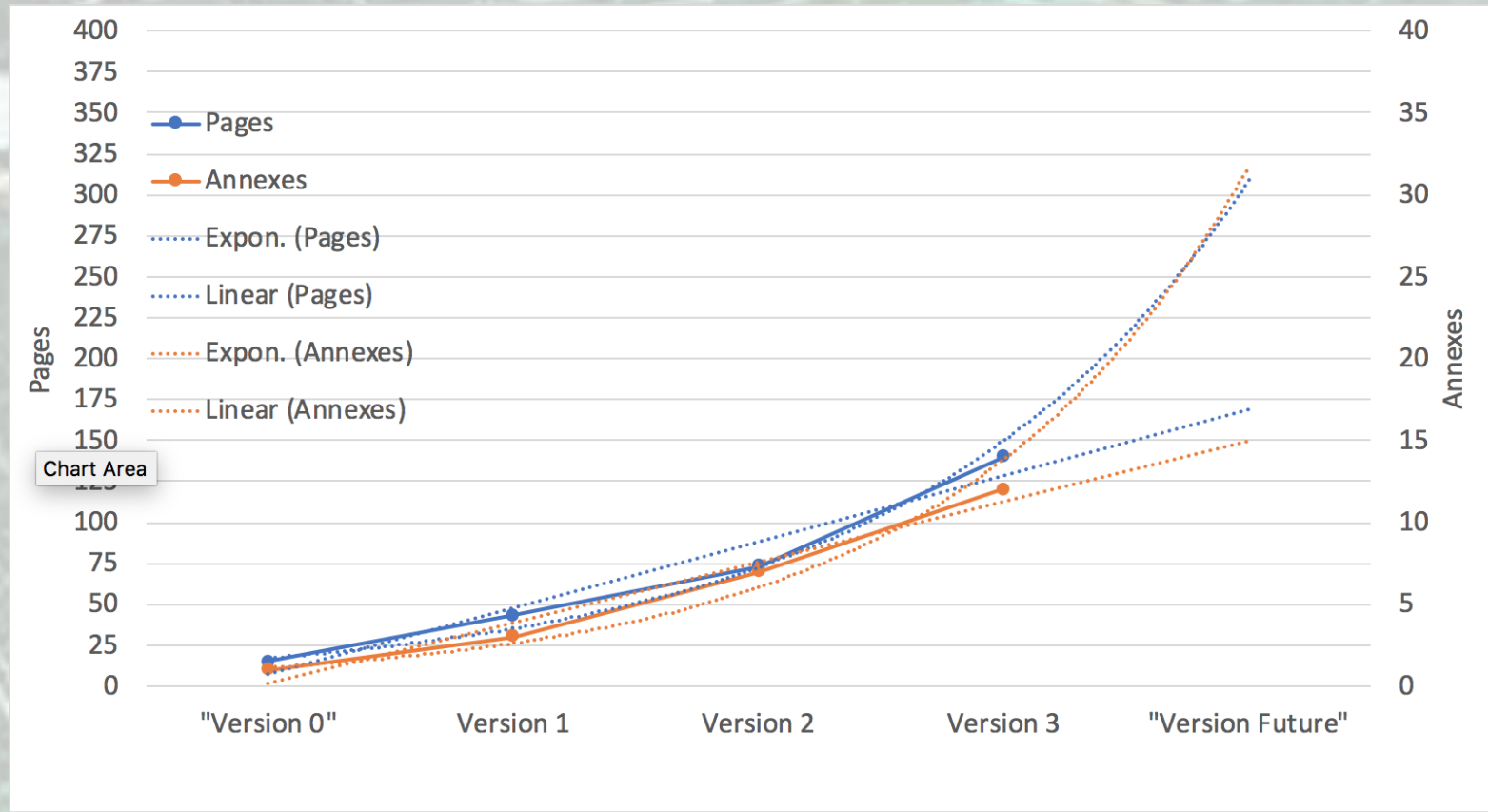
The ODM and the Space Assigned Numbers Authority (SANA)

- SANA provides a single central location to register "a variety of standards-related information, such as protocol identifiers, agencies, service and data providers, XML schema, a glossary of terms, and other information that is used across CCSDS"
- The SANA Registry did not exist at the time the ODMV1 and ODMV2 were developed
- NDM/XML schemas (including the schemas for the OPM, OMM, and OEM) were the first approved registry in February 2011
- NavWG is currently working to migrate the values for a number of ODM keywords to SANA Registries from static document annexes that are infrequently updated
 - Time systems, reference frames, components of orbital elements sets and covariances, orbit centers, attitude parameters
- Work is currently in progress and will be unveiled in the ODMV3, or possibly earlier

Orbit Data Messages "Version Future"

- Interoperability and cross-support make consistency in exchange standards essential
- Maintaining consistency from one standard to another can be challenging
- For example, Re-Entry Data Message (RDM) standard inherits data items from Conjunction Data Message (CDM) standard, which inherits data items from ODM
- At times various small inconsistencies have crept in, despite efforts to avoid
- Late in 2014, the informally proposed notion of a "universal, modular message" arose
- Wishful thinking?... but as ODMV3 has evolved the concept seemed more plausible
- Users combine one or more standardized message components within a single composite message, tailored to achieve specific mission needs
- Similar to NDM/XML "combined instantiation", concept allows a fusion of various pre-existing NavWG standards, with building block granularity smaller than in NDM/XML
- It is a rather complete break with most ODMV1 2004 conventions
- May present conversion challenges to those agencies which currently process ODMs, and may require explanatory ICD discouraged by CCSDS Engineering Steering Group
- "Modular message" concept still in early formative stages, but feasibility increasing

Growth of the ODM (Pages and Annexes)



Conclusion

- The ODM is the most successful and most broadly infused of the NavWG standards
- We have described its evolution...
 - From a "non-message" (ODM "Version 0")
 - To a relatively short, simple standard with 2 messages (ODMV1)
 - To a more complex standard with 3 messages (ODMV2) and XML instantiations (NDM/XML)
 - To a much more complex and richly featured standard with 4 messages (ODMV3)
- In transition to "Navigation Data Message of the Future", ODM could cease to exist as a separate document, replaced by a flexible, "building block" style message framework
- Represents partial return to the style of the original ODM "Version 0"
- The evolving ODM has encompassed an increasingly broad number of use cases
- As space agencies and operators put more and more spacecraft into orbit at Earth, Moon, and Mars, there will be increased need for regular ephemeris data exchange
- ODM is the primary international standard for spacecraft trajectory exchange in interoperable, cross-supported space flight dynamics operations